Iterative Receiver with Joint Channel Estimation and Decoding in LTE Downlink

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Abstract. In this paper, an iterative receiver using joint channel estimation and channel decoding is proposed for LTE downlink. In each iterative process, a modified LMMSE estimator is adopted to estimate the channel gain based on pilots as well as signals fed back from Turbo decoder. In contrast to a traditional LMMSE estimator, the modified estimator can make more precise channel estimation because a smaller spacing interpolation is performed with the help of feedback signals. The estimator and the decoder provide each other more accurate information in an iterative way, thus the performance of the receiver is improved. Three distribution patterns of the signals fed back from Turbo decoder with different density is compared, and the one with medium density is demonstrated to be the best by simulation results. To reduce the computational complexity of the receiver, cyclic redundancy check (CRC) is used to early stop the iteration. Simulation is done according to LTE physical layer specifications and the results show that the iterative receiver can provide about 50% accuracy improvement compared with a non-iterative receiver when SNR is 10dB. At the same time, the iterative receiver's computational complexity is in the same order of magnitude as the non-iterative receiver.

Keywords: LTE, iterative receiver, channel estimation.

1 Introduction

Recently, iterative signal processing becomes an attractive idea in the field of wireless communications. It is realized that Turbo principle can be applied to the design of iterative receivers. Now, there exist several schemes applying iterative signal processing in wireless communications such as Turbo equalization [1], iterative joint channel estimation and decoding [2], iterative multiuser detection [3].

In an iterative receiver in LTE downlink, channel estimator is a crucial module. Now, there are several channel estimation methods, such as LS (Least Square), LMMSE (Linear Minimum Mean Square Error) [4] and DFT-based (Discrete Fourier Transform based) [5]. LS is the fundamental channel estimation method which neglects the effect of noise so that its accuracy is low. LMMSE is a de-noising channel estimation method which takes advantage of channel correlation, and it is widely used for its high accuracy.

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In this paper, we present an iterative receiver with joint channel estimation and decoding. The receiver's performance is improved through iterations because the channel estimator and the decoder can provide each other more accurate information.

Iteration stopping criterion is an important issue in iterative receivers. Usually, iteration stops when it reaches a maximum iteration number, which has a high computational complexity. An iteration early stopping criterion is present in this paper to reduce the complexity.

The rest of the paper is organized as follows: in section 2, the considered system is described. Section 3 discusses the proposed iterative receiver. The receiver's performance is evaluated in section 4 and the conclusion is made in section 5.

2 System Description

In LTE systems, pilot assisted channel estimation is employed. According to 3GPP specifications [6], pilots locate at the 0th and the 5th OFDM symbols in time domain and every sixth carrier in frequency domain. In this paper, we denote complex symbols at each resource element (RE) by $X_{l,k}$, where l represents the OFDM symbol index and k represents the subcarrier index($l \in \{0,...,L-1\}, k \in \{0,...,K-1\}$).

After being generated, the signal is transmitted over a wireless multipath Rayleigh fading channel whose channel impulse response is:

$$h(\tau,t) = \sum_{i=0}^{M-1} \alpha_i(t)\delta(\tau-\tau_i) \tag{1}$$

In (1), $h(\tau,t)$ is the response measured at time t to an impulse input at time delay τ, $\alpha_i(t)$ is wide-sense stationary complex Gaussian random process, representing the ith propagation path gain at time t, obeying Rayleigh distribution. M denotes the total number of resolvable paths. For the convenience of analysis, without a loss of generality, we assume that:

1. The wireless channel is static within an OFDM symbol but varies for different OFDM symbols;
2. Timing and frequency offsets are completely eliminated.

At the receiver, the received signal of the lth OFDM block and kth carrier after Fast Fourier Transform (FFT) is:

$$Y_{l,k} = X_{l,k} \cdot H_{l,k} + W_{l,k} \tag{2}$$

In (2), $W_{l,k}$ is fast Fourier transformed zero-mean complex additive white Gaussian noise. In the following-up modules, $Y_{l,k}$, combined with estimation of $H_{l,k}$, is used to calculate the original signal.

3 Design of Iterative Receiver with Joint Channel Estimation and Decoding

In this section, an iterative receiver with joint channel estimation and decoding in LTE downlink is proposed. We first describe the structure of the iterative receiver and analyze the iterative process. Since the traditional LMMSE estimator is based on pilots, in order to apply it to iterative process, we use a simply modified LMMSE estimator based on both pilots and feedback data. For the sake of reducing the receiver's complexity, we propose an iteration early stopping criterion, which imposes CRC.

3.1 Iterative Receiver and Iterative Process

The block diagram of the proposed iterative receiver is depicted in Fig.1. Code block is detected in an iterative way. At the *i*th iteration, the iterative process is performed as follows:

First, estimated channel gain { $\hat{H}^{(i)}$ }is obtained using LMMSE algorithm and time and frequency interpolation. In the initial stage (i=0), LMMSE estimation is performed based on pilots, from the first iteration on (i>0), it is performed based on both pilots and data fed back from Turbo decoder. Second, QPSK symbols { $\hat{X}^{(i)}$ } are detected using estimated channel gain and received signal { $\hat{Y}^{(i)}$ }. Then, { $\hat{X}^{(i)}$ } are converted to bit stream { $\hat{C}^{(i)}$ } by QPSK demodulation and RE demapping (pilots are also discarded in RE demapping module). { $\hat{C}^{(i)}$ } is decoded in Turbo decoder, generating { $\hat{D}^{(i)}$ }. Errors are corrected completely or partly in this step. At last, a judgment is made to determine whether the iterative process goes on or not. If the process goes on, transmitted signal { $\tilde{X}^{(i+1)}$ } is reconstructed by Turbo coding, QPSK modulation, and RE mapping.

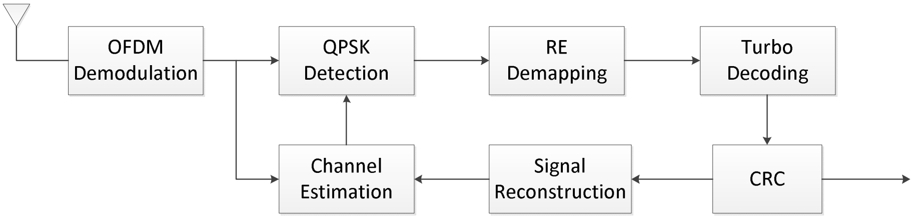


Fig. 1. Block diagram of the proposed iterative receiver

Through the iteration goes on, the receiver's performance is improved because the channel estimator and the decoder tend to provide each other more accurate information. For a non-iterative receiver, channel estimation is made just based on pilots and its accuracy is limited. However, for the proposed iterative receiver, channel estimation is made not only based on pilots but also based on error corrected symbols fed back from Turbo decoder, so it can achieve more accurate channel estimation. Also, the Turbo decoder can provide more reliable error corrected results because its input coded bits are produced using more accurate channel estimation.

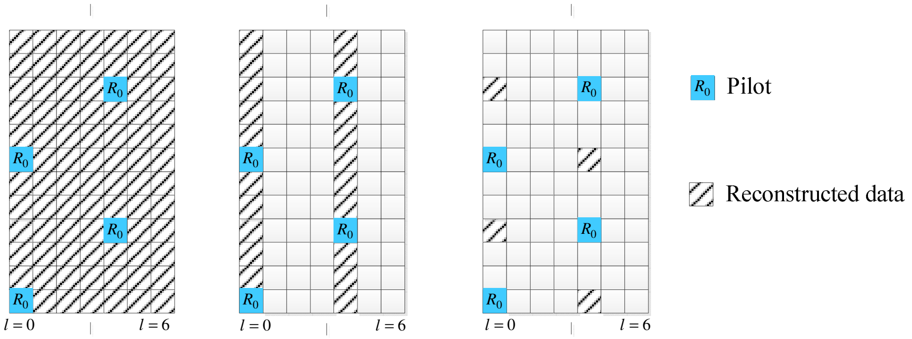
3.2 Channel Estimator in the Iterative Process

Since the traditional LMMSE estimator is based on pilots, in order to apply it to iterative process, we use a simply modified LMMSE estimator based on both pilots and data fed back from Turbo decoder:

$$\hat{\boldsymbol{H}}_s^{(i)} = \mathbf{R}_{H_sH_s}(\mathbf{R}_{H_sH_s} + \frac{\beta}{SNR}\mathbf{I})^{-1}\tilde{\boldsymbol{H}}_s^{(i)} \tag{3}$$

where subscript s denotes both pilot and reconstructed signal. $\hat{\boldsymbol{H}}_s^{(i)}$ denotes LMMSE channel estimation results. $\mathbf{R}_{H_sH_s} = E\{\boldsymbol{H}_s\boldsymbol{H}_s^H\}$ is channel autocorrelation matrix. $\tilde{\boldsymbol{H}}_s^{(i)}$ is the LS channel estimation.

We consider three reconstructed data distribution patterns fed back to the modified estimator, which is shown in Fig.2.



(a) (b) (c)

Fig. 2. Reconstructed signal distribution pattern

The pilots and reconstructed data distribution pattern shown in Fig.2 has different density. In the modified estimator, after LMMSE estimation, frequency and time interpolation is made respectively when we consider pattern (c). When we come to pattern (b), only time interpolation is needed, while in pattern (a), no interpolation is needed.

3.3 Iteration Early Stopping Criterion

For an iterative receiver, iteration stopping criterion is an important issue. Usually, a fixed number *N* is given and the iteration stops when it is processed *N* times. However, as the computational complexity of each iterative process is in the same order of magnitude, if the iteration goes on *N* times, the computational complexity is almost *N* times as the non-iterative receiver, resulting in a large processing delay.

In LTE specification [7], CRC parity bits are added to the tails of a code block for error detection. In the proposed iterative receiver, we also apply CRC to the iterative process. CRC checksum is calculated in each iterative process, if the checksum is right, the iteration early stops regardless of whether the receiver reaches the maximum iteration time *N*, because the correctly received code block doesn't need to be calculated again in an iterative manner any more. So, by applying early stopping criterion, the receiver's complexity can be reduced without accuracy reduction.

4 Performance Evaluation

To assess the performance of the proposed LTE downlink receiver, link level simulation is conducted. The transmitted signal is generated according to LTE specification [6]. We choose simulation scenario to be wireless PedB channel, with a 5Hz Doppler frequency and a 1/3 channel coding rate.

Fig.3 shows BLER over Signal to Noise Ratio (SNR). We can see that: the iterative receivers outperform non-iterative receiver. When the maximum iteration time *N* is set to 3, the receiver performs better than the case that *N*=1. This result confirms that the iterations provide accuracy improvement. It can be also seen that reconstructed data distribution pattern also affects the receiver performance: receiver with pattern (b) has a higher accuracy than pattern (a) and pattern (c). So the receiver should apply pattern (b) and the BLER will drops about 50% through the iterations when SNR is 10dB.

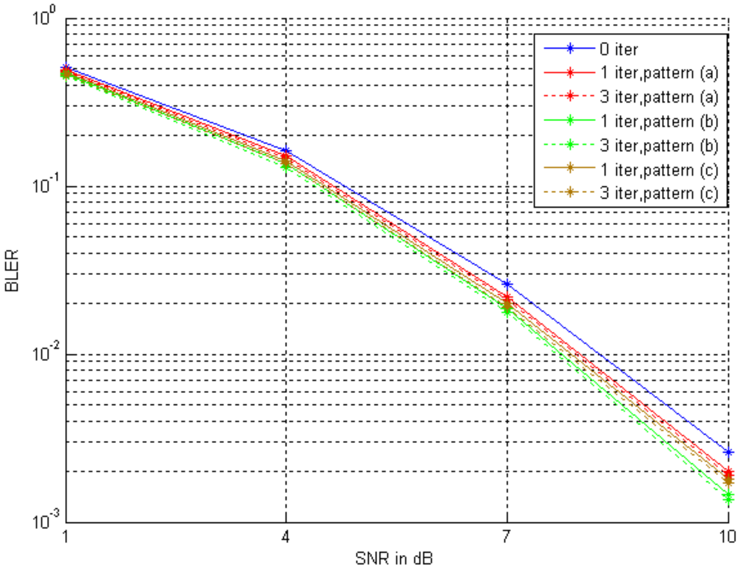


Fig. 3. BLER performance with varying SNR

Now, the computational complexity is discussed. We can see in Fig.3 that BLER is about 0.003 in the initial stage (SNR=10dB), meaning about 99.7% of the code blocks can early stop the iteration in the initial stage. For the remaining 0.3% of the code blocks, iteration is performed. However, these blocks cannot strongly affect the overall computational complexity of the iterative receiver because their proportion is too small. So, compared to non-iterative receiver, there is not an obvious computational complexity increase in the proposed iterative receiver.

5 Conclusion

In this paper, an iterative receiver with joint channel estimation and decoding in LTE downlink is proposed. The simulation results show that, in contrast to a non-iterative receiver, the iterative receiver can achieve about 50% accuracy improvement when SNR is 10dB. At the same time, the iterative receiver's computational complexity is in the same order of magnitude as the non-iterative receiver.

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